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FIRST QUARTERLY REPORT

DEVELOPMENT OF CADMIUM SULFIDE

THIN FILM PHOTOVOLTAIC CELLS

BY

F. A. SHIRLAND, F. AUGUSTINE and W. BOWER

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-6461

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ELECTRONIC RESEARCH DIVISION

CLEVITE CORPORATION

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Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Space Power Systems Division
L. R. Scudder

CLEVITE CORPORATION
Electronic Research Division
540 East 105th Street
Cleveland, Ohio 44108

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

DEVELOPMENT OF THIN FILM CdS PHOTOVOLTAIC CELLS

First Quarterly Report
October 15, 1964 through January 14, 1965
Contract No. NAS3-6461

INTRODUCTION AND SUMMARY *17538*

The present study is concerned primarily with the development
of the backwall insulating plastic substrate thin film CdS solar cell
with the objective of achieving practical large area cells of greater
than 4% conversion efficiency. In addition, certain design variations
including the frontwall plastic substrate cell and the backwall-frontwall
combination cell are to be evaluated to determine their feasibility,
advantages, and limitations as low cost large area thin film cells for
space use. A few selected problem areas of the frontwall metal sub-
strate cell were also included in this program.

In this first quarter a calibration has been made of the evapora-
tion conditions for the preparation of double-layer CdS polycrystalline
films. A few cells made from such films have shown that these films
can be used to secure lower sheet resistance while maintaining high
open circuit voltage. Large area backwall cells of this design gave
efficiencies up to 2.0%, but the parameters have by no means been
optimized and there are indications that the technique can be con-
siderably improved. A few frontwall-backwall combination cells
were constructed using double-layer CdS films that gave initial
efficiencies up to 3.5%.

The feasibility of a frontwall metallized plastic substrate cell
has been demonstrated, but the first few cells of this construction
were only just over 1% in efficiency due, it is believed, to the high
resistance of the metallized layer.

Among several alternate methods for contacting the barriers of
frontwall metal substrate cells that were evaluated, the cemented mesh
grid method gave best results and seems most practical in the long
run.

1

BACKWALL PLASTIC SUBSTRATE CELL

1. <u>Background and Objective</u>

This contract is a continuation of two years of research and development on two earlier NASA contracts. The earlier work was summarized in the final report on Contract NAS3-2795 which at this writing is in reproduction. The main emphasis of the investigation has been on the development of the backwall plastic substrate CdS thin film solar cell.

During the earlier work methods were developed for vacuum evaporating adherent CdS films onto specially prepared polyimide substrates and processing these into backwall thin film solar cells. The feasibility of the construction was demonstrated and cell efficiencies of over 4% were indicated. The construction showed potential advantages of very high specific power to weight ratios for solar cell arrays. Also very low costs per watt were indicated, since the design would eliminate the two most expensive ingredients of the frontwall metal substrate thin film cell (the electroformed metal mesh and the molybdenum substrate) which itself has low cost per watt potential.

The polyimide plastic film has markedly superior resistance to damage from high energy particulate radiation and from ultraviolet radiation over other known transparent plastic materials. So even though the backwall cells might have lower conversion efficiencies initially, due to their restricted spectral response, they might yield far more output over extended periods of time.

The main purpose of the present contract is to extend the work of the previous contracts to secure practical large area plastic substrate cells reproducibly greater than 4% in conversion efficiency. Selected approaches to this goal include the use of double layer CdS films, the improvement of the barrier formation process and the barrier contact, and the use of grids beneath the CdS layer to lower its sheet resistance. Progress has been made on each of these approaches.

2. Slurry vs. Chemiplated Barriers

A comparison was made of both backwall and frontwall cells whose barriers were made by the Cu_2O slurry process and the CuCl chemiplating process. Nearly identical results were obtained for the two methods of barrier formation.

In one case the cells are heated over a hot plate to about 90°C and a water slurry of pure Cu_2O painted on with a soft bristle brush, or the cell is dipped in a water slurry of Cu_2O preheated to 90°C. In the other case the cell is dipped in a solution of CuCl preheated to about 90°C.

It appears that the two processes are essentially the same thing, the difference being in the source of the cuprous ions which react with the CdS surface. Of course, in the slurry process there is excess material on the CdS surface which must be removed, but this does not change the nature of the barrier formation process itself. For convenience therefore, the CuCl dip process has been adopted as standard for all the subsequent work on this contract.

3. Conductive Silvers

A number of conductive silver compositions were checked for electrical conductivity and for compatibility with CdS cell barriers. This study was necessitated by the erratic results that had been obtained from various backwall cells with silver print contacted barriers. A number of those cells gave markedly higher efficiencies when a piece of electroformed gold grid was laid over the silver print collector electrode and the whole laminated between sheets of Mylar foil.

Several silver compositions that were available in our laboratory were coated onto pieces of H-Film and the bulk resistivity measured after air drying for about 3 hours at room temperature, then after curing for approximately 5 minutes in a 250°C oven, and then finally after lamination for approximately 10 minutes at 230°C and 100 psi. The data are given in Table I.

Lowest bulk resistivity of 2×10^{-5} ohm-cm was obtained for Waldman #3030 silver after lamination. The various other silvers

3

TABLE I

BULK RESISTIVITY OF VARIOUS SILVER COMPOSITIONS

Resistivity in ohm-cm x 10^{-5}

Composition	Air Dried[*]	Oven Cured[**]	Laminated[***]
Waldman 3030	25.2	1.8	2.0
DuPont 8079	98.	8.7	5.6
8072	3780.	13.8	11.9
5815	51.8	16.4	8.2
8030	75.6	11.1	15.1
Fenwal 206	966.	1750.	-- (bad contact)
Emerson & Cuming 58C	18410.	79.	42.
56C	1590.	102.	79.8

[*] Approx. 180^{+} min. @ room temperature.

[**] Approx. 5 min. @ 250°C.

[***] Approx. 10 min. @ 230°C and 100 psi.

4

tried ranged up to 40 times higher in resistivity. Nearly all of the silvers reduced their resistivity on oven curing, and reduced them further after lamination. Small differences in bulk resistivity of the silvers might be compensated for by using a thicker layer of the silver, but in this case the differences appear to be severe.

Three of the better silvers from the standpoint of bulk resistivity, plus one additional silver (General Cement's #21-1), were therefore evaluated with respect to the kind of contact they made to barriers of actual cells. The data are given in Table II. Each of these cells were about 1" x 1" in size cut from the same H-Film substrate evaporated CdS film with evaporated gold peripheral electrodes. The cells were measured after air drying of the silver paste p-electrode layer, after oven curing, and after lamination.

The voltage on all of these cells was low, but this is normal for these highly doped CdS films on H-Film substrates. Surprisingly, all of the cells deteriorated after oven curing of the silver, and some deteriorated very badly. However, all of the cells recovered after lamination, though some had to be laminated several times to reach their best output.

The best results on this test were obtained with General Cement's 21-1 silver composition. However, only a few cells were involved in these tests and a repeat experiment comparing the performance of several cells with the Waldman 3030 silver against the General Cement 21-1 silver should be made.

4. Stability Data

A periodic check was made of (desiccated) shelf stability of small area (1" x 1" size) backwall film cells on H-Film substrates.

Some cells of 2.5 to 3.0% efficiency showed slight deterioration over periods of 2 months and more. Others showed severe deterioration in 2 to 3 weeks time. However, when these were relaminated, they gave efficiencies well in excess of their original values (the best of these was over 4.0%). The relamination appears to have improved the shelf stability of these also, making it appear probable that the cells

5

TABLE II

PERFORMANCE OF BACKWALL PLASTIC SUBSTRATE CELL WITH
BARRIERS CONTACTED USING VARIOUS SILVER COMPOSITIONS

Composition	OCV	J	F. F.[*]	Eff.	Remarks
	v	ma/cm^2	%	%	
A. Air Dried					
Waldman 3030	.35	15.7	53.	2.7	
G. C. 21-1(a)	.34	14.4	46.	2.1	
21-1(b)	.37	16.0	48.	2.7	
21-1(c)	.36	16.1	56.	3.0	
DuPont 8072	--	--	--	--	Not tack-free
8079	.33	14.8	45.	2.1	
B. Oven Cured 5 min. @ 250°C.					
Waldman 3030	.15	4.2	30.	0.2	
G. C. 21-1(a)	.31	11.2	41.	1.4	
21-1(b)	.35	11.7	46.	1.9	
21-1(c)	.34	11.8	43	1.8	
DuPont 8072	.22	5.0	31.	0.4	
8079	.23	7.7	31.	0.6	
C. Laminated					
Waldman 3030	.27	15.9	51.	2.2	Laminated twice
G. C. 21-1(a)	.28	15.8	46.	2.1	Laminated twice
21-1(b)	.34	18.8	49.	3.2	Laminated 4 times
21-1(c)	.34	19.7	53	3.6	Laminated 4 times
DuPont 8072	.32	19.0	53.	3.2	Laminated 4 times
8079	.30	16.2	52	2.5	Laminated 3 times

[*]F. F. = fill factor.

6

were insufficiently heat treated originally. A longer hold during the lamination cycle is now being tried to see if the condition can be taken care of in this manner.

Figure 1 is a plot of the output efficiency for the various cells on this test. All of the data plotted is for groups of three 1" x 1" cells in series. (The data was taken also for many of the cells singly, but is not plotted here.) For clarity, the ordinates are displaced for each group of cells. The scale is 1% efficiency per 1/2". The initial and final efficiency figures are given for each group of cells.

5. Double Layer Films

While many small area cells on insulating H-Film plastic substrates have been fabricated with conversion efficiencies of 3 to 4%, and a few over 4%, no large area film cells were obtained in excess of about 1.5%. It has become evident that it is the sheet resistance of the n-type CdS polycrystalline layer that so limits the output of the larger area cells.

In an effort to get around this difficulty, more highly doped CdS films and thicker films have been used. For small area cells of approximately 1" x 1" size, 50 to 60 micron thick films of 0.06 to 0.08 ohm-cm CdS have given the best results to date. Such films yield cells with reduced voltage outputs (0.35 to 0.40 volts open circuit), but at somewhat higher than normal current levels (occasionally over 20 ma/cm^2 short circuit current). If still higher doping levels are used, the resistivity of the CdS film could be reduced to the range of 0.01 ohm-cm before the optical transmission is severely affected. However, at that point the cell voltage drops too far to secure high efficiency cells.

It is believed that the advantage of high cell voltage might be combined with low lateral electrical resistance if a high resistivity CdS film were laid down on top of a very low resistivity film. In this manner. it is hoped to secure large area CdS cells of 3" x 3" size on insulating substrates with efficiencies in the 4 to 5% range. The barrier would be formed on the high resistivity CdS yielding cell
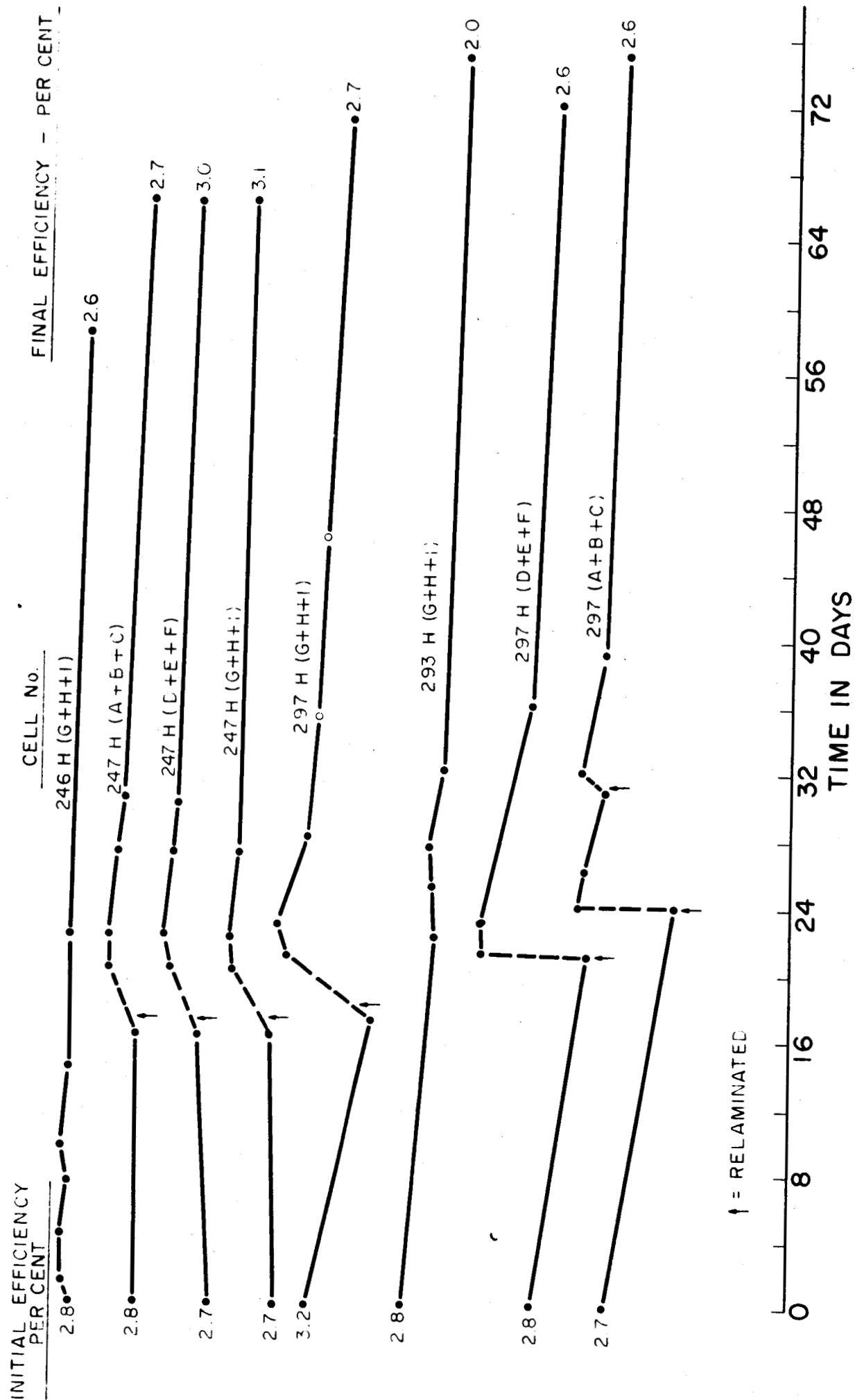
7

FIG. I. SHELF STABILITY OF BACKWALL PLASTIC SUBSTRATE FILM CELLS

ERD 8015

voltages of about 0.5 volts. Yet high lateral conductivity would be provided by the highly doped CdS film underneath (this is somewhat anologous to undoped CdS films on metal foil substrates as is used for the frontwall CdS thin film solar cell).

The first cut-and-try attempts to construct such a double layer film cell failed because the upper CdS layer peeled from the lower layer during subsequent processing. In the next attempts the upper layer was evaporated from a second set of sources immediately following and slightly overlapping the evaporation of the low resistivity underlayer. However, these cells also were low in output.

Lacking suitable rate monitors and film thickness monitors, the duration and extent of the evaporation of each layer could not be determined with reasonable accuracy. Therefore, a series of experiments were run to calibrate the conditions for evaporating separately known thicknesses and resistance levels for both the upper and lower CdS films. Since CdS films of 0.0010 to 0.0012" thickness were found to give satisfactory results for frontwall metal substrate cells, it was decided to try double layer films on insulating substrates with an overall thickness of 0.0012", with half the thickness for each layer.

Nominal resistivities of 0.01 ohm-cm for the lower layer and 100 ohm-cm for the upper layer were chosen. The doping levels in the starting material and the time, temperatures, and other evaporation parameters for securing such films separately were determined.

However, again, when the two layer films were constructed, relatively poor cell conversion efficiencies were obtained. But, in a few cases good open circuit voltages, in the range of 0.47 to 0.49 volts, were obtained. These cells had poor characteristic curves so that the efficiencies were low. There were a number of extraneous factors that crept into these experimental runs that are believed to have prevented a real evaluation of the concept of the double layer CdS film cell. One of these was pin holes in the upper CdS layer due to spattering of large particles from the evaporation sources. These pin holes were not evident visually at first but are believed to have opened up as it were during subsequent cell processing. Another

8

factor that crept in was a tendency for the large area CdS films on H-Film substrates to develop very fine cracks during subsequent processing. These cracks did not occur on the small area cells of 1" x 1" size. They are believed to be stress cracks due to a build up of the stresses resulting from the differential shrinkage of CdS and substrate on cooling to room temperature after evaporation.

As discussed in the following section of this report, when steps were taken to eliminate the stress cracks and the pin holes in the CdS films, the double CdS layers did start to yield higher cell outputs for the larger area cells. This study will continue in the next quarterly period.

6. Large Area Cells

During this first quarterly period the design of the large area backwall H-Film substrate CdS film solar cell has undergone a series of changes. These changes were somewhat forced, rather than comprising an orderly progression, in an effort to telescope the developmental efforts on this type of cell and to secure the higher efficiency levels that have already been attained for the frontwall metal substrate cell.

The initial goal for this phase of the effort was to establish the feasibility of the construction by securing at least one 3" x 3" backwall plastic substrate cell of 4% conversion efficiency. This goal was not quite achieved, but as a result of the effort it has been determined that it is chiefly the series resistance of the n-type CdS layer which has so far prevented the attainment of the goal. It appears that this difficulty can probably be circumvented. There are real advantages to be realized from so doing as this construction could yield much higher specific power to weight ratios than the front-wall metal substrate cell design and at the same time eliminate the electroformed precious metal collector grid and the molybdenum foil substrate which are the two most costly components of that design.

The initial configuration of the large area backwall H-Film substrate cell is illustrated in Fig. 2. This was essentially the design

Nickel n-electrode

Margin, bare CdS
(approx. 0.030")

Barrier, Covered
with Silver Print
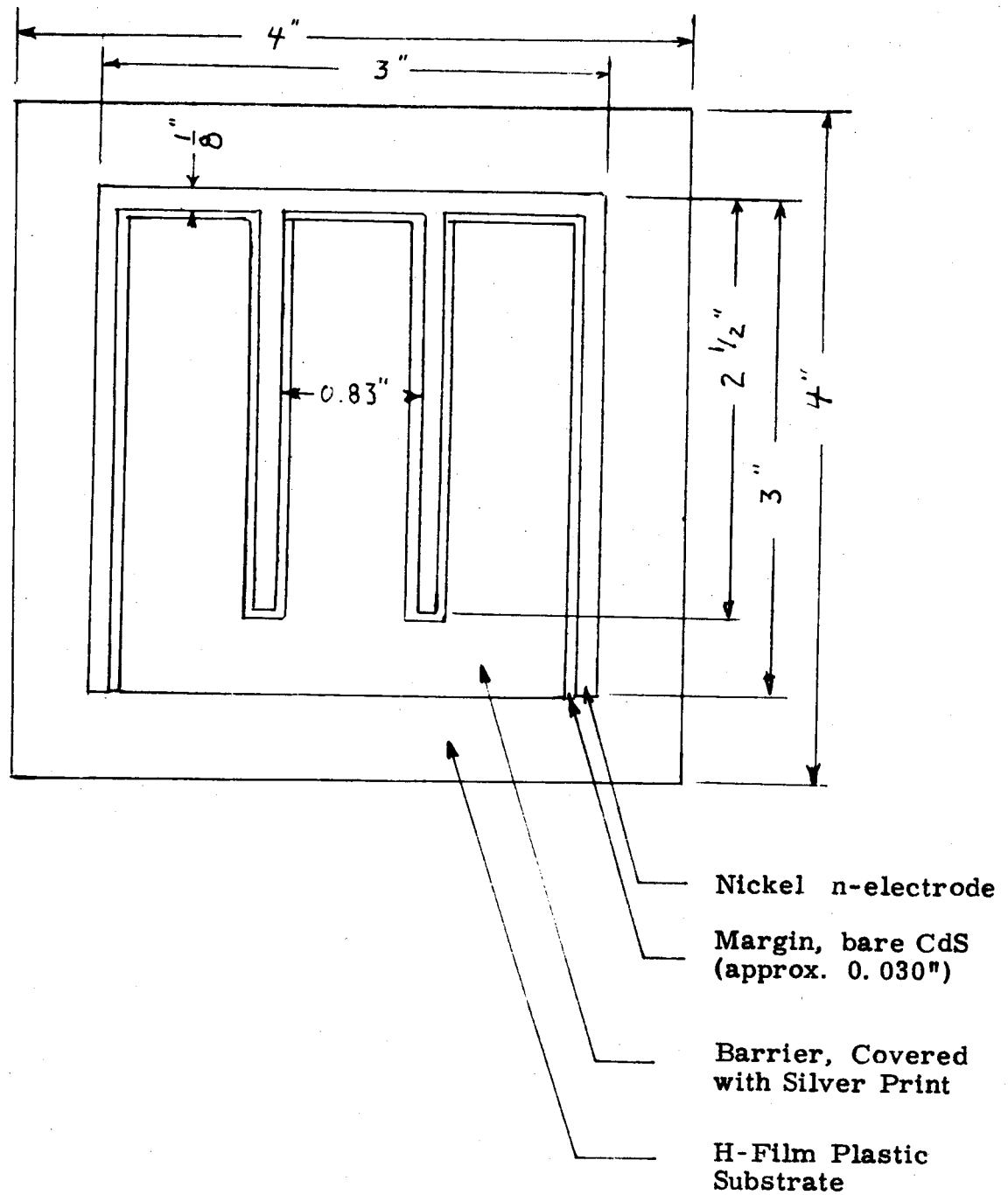
H-Film Plastic
Substrate

FIG. 2   BACKWALL PLASTIC SUBSTRATE LARGE
AREA FILM CELL CONFIGURATION

of the large area backwall insulating glass substrate film cell which was developed at the end the preceding contract. The "n" collector electrode runs around three edges of the CdS film and two comb-like fingers extend most of the way across the face of the cell, as shown. This geometry gives a maximum path of about 1 cm for electrons in the n-type CdS layer. The electroplated nickel n-electrode and the silver paint p-electrode are both on the upper surface of the cell and are separated by a margin of about 0.030". To improve the CdS film adhesion the H-Film substrate is lapped on one surface and given an $SnCl_2$ sensitizing treatment prior to vacuum evaporation. The CdS film is relatively thick (1.8 mils) and highly indium-doped to lower its resistivity to the range of .06 to .08 ohm-cm.

This general design was reasonably satisfactory when pyrex glass substrates were used during the previous contract, yielding cells of up to 3% conversion efficiency for areas of 4" x 4". However, in translating to the H-Film substrate the best cell obtained was 1.5% and this dropped to 0.9% when it was laminated to a protective upper plastic layer. On careful examination it was found that there were many fine cracks in the CdS film. These cracks tended to concentrate near the edges of the film close to where the H-Film was clamped in the substrate holder for evaporation (and subsequent processing) and where the film tended to "dish". However, they extended well into the barrier electroded area.

It is probable that these are stress cracks resulting from the differential shrinkage of the CdS and plastic substrate on cooling to room temperature after evaporation. These cracks had apparently not been experienced on the samll area H-Film substrate cells (1" x 1" size). The stress appears to build up over the larger areas and concentrate at the regions of maximum curvature. The recently improved CdS film adhesion probably aggravated this condition. During lamination the silver print was probably forced into the cracks thus causing numerous small internal shorting paths. In addition, the cracks must have increased the sheet resistance of the n-CdS layer.

A number of ideas for eliminating the stress cracks were tried. The cracks were virtually eliminated by a combination of reducing the clamping of the H-Film in its holding fixture, by reducing the thickness of the CdS layer to about 0.0012", and by reducing the temperature of the substrate during vacuum evaporation to 180°C.

However, the cells were still low in output, less than 1% efficiency. The shape of the I-V characteristic curves pointed to excessive series resistance as the obvious major cause. Several modifications in cell design, evaporation parameters, and electrode configuration were tried in an effort to reduce the series resistance. In one experiment, an electroformed gold mesh screen grid was pressed into an H-Film substrate and the CdS was evaporated on top of it. There were a few shorted areas of the finished cell, but these were located visually and eliminated. The resulting cell had an active area of 45 cm^2 and yielded 2.0% efficiency. Its OCV was 0.44 volts and SCC was 530 ma, but the fill factor was only 39% indicating either considerable series resistance still remaining, or partial shorting due to poor CdS crystal structure at the regions above the buried grid.

Several repeat runs of this construction with the gold grid beneath the CdS film were tried. On most of these difficulties were encountered with the grids coming away from the H-Film substrate and "sticking through" the evaporated CdS layer. A few that did not, or on which the adversely affected regions could be masked off from the rest of the film, gave moderate cell outputs. It was suspected that the buried gold grid might be making a high resistance or even partially rectifying contact to the n-type CdS. Nickel grids were then substituted for the gold grids and indications of better results were obtained.

BACKWALL-FRONTWALL CELLS

Several other variations were introduced at about this same time. First, to secure higher open circuit voltages for the cells than had been possible with the highly indium-doped CdS films, the double layer technique was added to the standard process. This, as described

above, consisted of a low resistivity CdS layer of about 0.01 ohm-cm evaporated over the nickel grid onto the lapped surface of the H-Film. Then a second CdS layer of about 100 ohm-cm resistivity was evaporated onto the second layer immediately following the first layer and without breaking vacuum. About 0.0006" thickness for each layer was adopted as standard. This technique was successful in raising the OCV of these cells to 0.45 volts and greater.

Second, because of the suspected presence of pinholes in the upper CdS layer that could cause shorting through of the silver paint layer to the low resistivity CdS underlayer, the barriers of some cells were contacted with 60 line per inch electroformed gold mesh grids.

These changes were partially successful and several cells in the range of 2.5 to 3.5% conversion efficiency were obtained, at least initially. These cells could be illuminated from either direction and hence operated in either backwall or frontwall modes. A comparison of two such cells yielded slightly better results for the backwall mode of operation in one case and the reverse in the other case. These are preliminary indications only and more data are required on higher efficiency cells before a definitive answer can be secured as to the relative output obtainable from the two different modes.

Cell No. 368H of 40 cm^2 area was laminated on January 5th and was of this construction. It was tested after two weeks as follows:

	OCV	S.C.C.	Max. Power	Eff.
Frontwall	0.47 V	11.8 ma/cm^2	93 mw	2.2%
Backwall	0.47 V	9.5 ma/cm^2	71 mw	1.8%

This cell was then delivered to Lewis Laboratory of NASA for their further test and evaluation.

FRONTWALL METAL SUBSTRATE CELL

1. Stability on Temperature Cycling

At the end of October, 1964, six frontwall molybdenum substrate CdS thin film solar cells were furnished to Lewis Laboratory, NASA, for thermal cycling test in vacuum. These were 3" x 3" size cells fabricated by a proprietary process at the Clevite Research Center. They measured between 4. 2% and 4. 9% in bright sunlight, prior to delivery. Slightly higher outputs on the average were obtained by NASA in direct sunlight a week later. These cells were constructed with 60 line per inch electroformed gold mesh grids held in pressure contact to the barriers with a Mylar-Capran plastic lamination.

Three of these cells were placed on NASA's standard vacuum thermal cycling test. This test consists of 15 minute alternate light and dark exposures in a 10^{-5} Torr or better liquid nitrogen cooled vacuum chamber. The light intensity is set to give a temperature rise of the cells to approximately 60°C. During the dark cycle, the cells cool to approximately -60°C. The output voltage of the cells on open circuit and across a 1 ohm load is monitored once during each light cycle. Previous cells of this general design have usually developed short circuits within a few hundred cycles. The purpose of this test was to determine if the slightly different design higher efficiency Clevite cells were more stable in this respect.

Of the three cells, one developed a partial short at 1950 cycles with both OCV and voltage under load dropping to about 25% of the initial value. The remaining two cells went on without any shorts developing and were removed from the test at 2920 cycles. There appeared to be a drop of about 20 to 25% of the initial output at that time, which seemed to occur as a steady decline in output throughout the period of the test. However, when removed from the test and measured under more accurately calibrated equivalent sunlight conditions, these cells were found not to have deteriorated at all, but rather to give slightly more output than when they were originally delivered. This was confirmed by measurements both at NASA and at Clevite. The data on these cells is given in Table III.

13

TABLE III

EFFICIENCY OF 3" x 3" FRONTWALL METAL SUBSTRATE CELLS
BEFORE AND AFTER TEMPERATURE CYCLING

	Before		After
Cell No.	Sunlight Test 10/23/64 at Clevite	Sunlight Test 10/20/64 at NASA	Tungsten Equiv. Sun Test 1/20/65 at Clevite
205	4.2%	4.31%	4.45%
211	4.3%	4.64%	--
213	4.2%	4.62%	4.56%
Ave.	4.2%	4.52%	

TABLE IV

EFFICIENCY OF 3" x 3" FRONTWALL METAL SUBSTRATE CELLS
BEFORE CONTINUOUS LOAD TEST

Cell No.	Sunlight Test 10/23/64 at Clevite	Sunlight Test 10/20/64 at NASA
201	4.9%	4.75%
203	4.4%	4.96%
219	4.2%	4.37%
Ave. 4.5%		Ave 4.69%

14

The apparent decay of output of the cells was first thought to be due to the aging of the tungsten lamps used to heat and illuminate the cells, but when these lamps were changed the output of the cells remained the same. It seems more likely that the spectral response of the cells may have shifted to favor the shorter wavelengths of light while on test thus showing a drop in output in the high infrared light used to heat the cells and yet giving higher output in equivalent sunlight. This possibility will be checked by taking spectral response measurements before and after the next temperature cycling test.

The remaining three cells delivered to NASA from this group were placed on a continuous load test. This test consists of constant illumination of the cells with four tungsten spot lamps through a 2" thick water filter at approximately sunlight intensity. The cells are connected to a resistive load and the output is read periodically. The data on these cells, before testing, is given in Table IV. The cells were still on test and showing no measurable loss in output after more than two months exposure.

2. Other Methods of Contacting Barriers

One of the tasks of the present contract is to develop an alternate means of contacting the barrier of the frontwall cell. It was thought that the shorting experienced on the standard construction cells during temperature cycling might be due to a rubbing action of the collector grids against the barrier with the expansion and contraction that would occur from wide temperature swings. Thus an alternate method of contacting might be free of the difficulty. Also, another type of contact might make practical the elimination of the clear plastic encapsulant which has a limited life in the high radiation space environment.

a. Evaporated Grids

A technique was developed for vacuum evaporating a 60 line per inch gold grid with approximately 80% open space between the grid lines. The method consists of placing a 60 line per inch

electroformed metal mesh as a mask against the barrier of frontwall cells and lightly spraying a fluorocarbon solution through the openings onto the barrier. The cell is then placed in a vacuum chamber and gold is vacuum evaporated onto the barrier. The gold adheres only to the portions not coated with the fluorocarbon spray. After evaporation the fluorocarbon is removed by washing in solvent.

This method gives excellent contacts and neat, well adherent, electrodes up to about 1 micron in thickness. Beyond this the gold starts to peel. Unfortunately, there is too much series resistance in a 1 micron thick metal grid of 80% transmission to carry the high currents of the large area cells without seriously affecting efficiency.

There is presently little hope of building up the thickness of evaporated contacts to the 10 to 15 micron minimum that would be required, hence this approach is not being pursued further.

b. Electroplated Grids

Unidirectional copper and silver grids were electroplated onto the barriers of frontwall cells and showed good lateral conductivity and made low resistance contacts. However, in every case the electroplating operation destroyed the photovoltaic properties of the cell. It may be that some ingredient in the electroplating baths tried is deleterious to the Cu_2S barriers, though a number of relatively simple plating baths were tried. It seems more likely that there is some characteristic of the chemiplated barriers that is incompatible with an electroplating operation. Similar experiences have been reported elsewhere. Further efforts with this method were indefinitely postponed because of better success with cemented grids.

c. Cemented Grids

Encouraging results were obtained by cementing electroformed metal mesh grids in place with a conductive epoxy silver composition. Waldman No. 3021 was used, but probably many other conductive epoxies would work as well. The following technique was

16

developed which gave fairly satisfactory results. The epoxy cement is spread out to a thin even layer on a flat glass plate using a rubber squeegee. A standard 60 line per inch electroformed metal (gold or copper) mesh grid is then placed smooth side down onto this layer with an even rolling motion. The grid is permitted to sink into the paste layer slightly so that one side only is completely in contact. Then it is peeled off and transferred to the barrier of the cell to be contacted. The epoxy cement is then cured with a light flat weight holding the grid against the cell barrier.

The technique was worked out with a number of small area cells until very little spreading or smearing of the epoxy was encountered, and most of the cells were in excess of 4% efficiency. Then a total of nine standard 3" x 3" cells were processed in the same manner. On these larger cells there was some slight spreading of the epoxy silver cement with a resultant loss of up to about 15% in the transmission of light through the cemented grids. The cells were later laminated in plastic for convenience and for protection of the barriers, however, the lamination was not needed for the contact to the barrier.

The efficiency of these cells was slightly less than that of the standard 3" x 3" frontwall cells made at the same time with the grids held in pressure contact by the laminated plastic layer. They ranged from 3.6% to 4.9% and averaged 4.1%. The data on these cells is shown in Table V. They were stored for up to 9 days in a desiccator cabinet, tested as shown, and then delivered to NASA for temperature cycling and other testing.

This technique appears to be reasonably practical and could probably be developed to an economic production process. Further work with this method of contacting will now depend upon favorable results from the NASA evaluation of them.

17

TABLE V

OUTPUT OF 3" x 3" FRONTWALL METAL SUBSTRATE CELLS WITH CONDUCTIVE EPOXY CEMENTED GRIDS

Cell No.	Area (cm^2)	OCV (volts)	SCC (ma/cm^2)	Max. Power (mw)	Efficiency (%)
315D	48.9	0.45	14.6	204	4.9
320D	48.3	0.415	15.9	191	4.0
331A	49.3	0.445	15.6	221	4.5
331D	48.3	0.415	16.2	180	3.7
333A	47.5	0.46	15.7	209	4.4
336B	48.6	0.43	14.5	189	3.9
337B	48.3	0.43	15.9	189	3.9
337C	46.8	0.45	12.5	172	3.7
339B	48.6	0.425	14.7	176	3.6

Notes: Cells 336B, 337C and 339B had 60 lpi gold grids, remaining cells had 60 lpi copper grids.

Efficiency test run 1-15-65 in tungsten light equivalent to 100 mw/cm^2 terrestrial sunlight.

FRONTWALL PLASTIC SUBSTRATE CELL

One of the major advantages of the frontwall metal substrate cell over the backwall insulating substrate cell is that the sheet resistance on the "n" side of the barrier can be kept very low because the substrate itself is an excellent conductor. Another advantage is that both extrinsic and intrinsic response is obtained. However, the disadvantage is that the metal substrate is much heavier than required for the job (for strength and handling) and this lowers the power to weight ratio and increases the cost.

If the metal foil were replaced by metallized plastic foil the disadvantages would be overcome. This is the purpose of the frontwall plastic substrate cell design.

Metallized H-Film plastic substrates were ordered from a commercial supplier of specialized evaporated coatings. This was the EMC Technology Company of Philadelphia, Pa. Three different types of gold coatings were received: a thick doped gold layer, a tin-doped gold layer, and a "stabilized" gold layer which was the vendor's proprietary coating. These were measured in our laboratory at 0.8, 4.0, and 1.0 ohms per square sheet resistance respectively.

By our preliminary calculations the sheet resistance of the substrate should be below 0.5 ohms per square, and preferably down to about 0.2 ohms per square in order to secure high efficiency large area frontwall thin film cells.

Each of the different substrates was evaporated with a standard undoped CdS polycrystalline film and processed into 3" x 3" solar cells. As expected, they gave low efficiencies, 1 to 2%. From the IV curves it was evident that the cell outputs were limited by the series resistance. The data on these is summarized in Table VI. Cell Nos. 371H and 374H were delivered to the Contract Monitor as state-of-the-art samples of this construction.

Additional metallized H-Film plastic substrates have been ordered with maximum sheet resistances specified in the 0.3 to 0.5 ohms per square range. Some other coatings including nickel and aluminum may also be tried.

TABLE VI

OUTPUT OF 3" x 3" FRONTWALL CONDUCTING PLASTIC SUBSTRATE CELLS

Cell No.	Area (cm^2)	OCV (volts)	SCC (ma/cm^2)	Max. Power (mw)	Eff. (%)	Substrate Coating
370H	40. 2	0. 39	10. 0	44	1. 1	Thick gold
371H	40. 3	0. 44	10. 3	56	1. 3	Tin-doped gold
374H	38. 4	0. 39	9. 4	47	1. 3	Stabilized gold
375H	42. 3	0. 46	10. 6	67	1. 6	Thick gold